GROUNDWATER CONTAMINATION FROM CEMETERIES CASES OF STUDY

L. Rodrigues [1] and A. Pacheco [2]

[1] *Departamento de Zoologia e Antropologia da Faculdade de Ciências da Universidade do Porto, Portugal; luisa_rodrigues@mail.pt*
[2] *Departamento de Geologia Sedimentar e Ambiental do Instituto de Geociências da Universidade de São Paulo, Brasil; apacheco@usp.br*

KEY WORDS
Groundwater contamination; Cemeteries; Burial; Human body decomposition

ABSTRACT

This paper presents a study of special interest because up to now there are no publications in Portugal, which investigate the impacts of physical, chemical and microbiological groundwater contamination caused by cemeteries.
The question of the potential risk for adverse impact of cemeteries on ground and superficial water has never received enough attention in our country. However, this risk may exist when cemeteries are placed in groundwater areas that are vulnerable to contamination.
In order to reduce the risk, planning for new cemeteries should evaluate geological and hydrogeological aspects, which constitutes a gap in the Portuguese legislation. This and other considerations about Portuguese legislation concerning cemeteries have been discussed.
This work reports a study that was carried out between September 2000 and September 2001, in three different areas to understand the risk of groundwater contamination from cemeteries placed in different lithology, hydrogeology and geographic areas: Querença and Luz de Tavira located in Algarve and Seixas located in Minho.
Several tests were conducted every two months: physical, chemical and bacteriological variables were analysed in several bored wells placed in the area of cemeteries. The physical-chemistry variables analysed were: temperature, pH, electrical conductivity, nitrites, nitrates, ammonium ion, chloride, oxidizability, total phosphorous, calcium, magnesium, hardness, sulphates, sodium, potassium, total zinc, total lead and TOC. The microbiological indicators analysed were: total and fecal coliform, fecal streptococcos, heterotrophic bacteria (22ºC and 36 ºC), clostridia and proteolytic bacteria. Additionally the geophysics in the area around Querença cemetery was studied.
The results from Querença were not conclusive with respect to determining the influence of cemetery contamination on groundwater, despite the fact that high levels of chemical and bacteriological contamination were detected in all the bored wells sampled. Since it is a karst aquifer and due to the existence of many septic tanks in the area, this can mask the impact from the cemetery. Although, there are indications that the closest sampling point from the cemetery must be under the influence of the cemetery, specially with shallow groundwater after periods of precipitation.
The analysis from the cemetery water of Luz de Tavira and Seixas had higher levels of bacteriological (both cemeteries) and physical-chemical values (Luz de Tavira) than the water from other sampling points further away from the cemetery, which indicated the impact from these cemeteries on groundwater quality.

INTRODUCTION

The question of the potential risk for adverse impact of cemeteries on ground and superficial water has never received enough attention in our country. Consequently, cemeteries have never been perceived as having a significant potential contaminant effect in the environment. In Portugal, cemeteries are, often located close to populations, in the radius of influence of water sources.

Literature related with this aspect of contamination of groundwater has been found to be limited (BASTIANON *et al*., 2000; BECKS, 1997; ENGELBRECHT, 1998; FISHER and Croukamp, 1993; MATOS, 2001; MATOS and PACHECO, 2000; PACHECO *et al*., 1991; VAN HAAREN, 1951).

The biological process of contamination

Cemeteries are laboratories of decomposition. The human body is a complex structure therefore the final products of decomposition are several: volatile fatty like acid butyric and propionic, primarily breakdown products of both muscle and fat (VASS *et al*., 1992), amino acids, fatty acids, ptomaine (skatole, indol, cadaverine and putrescine) and end products like: ammonia, ammonium compounds, hydrogen sulphide, mercaptan, methane, carbon dioxide and phosphoric acid.

When ever a cadaver is buried there are several alterations. Soft tissue starts to decompose a few hours after death due autolyse mechanisms (VASS *et al*., 1992), followed by a process of fermentation due to the action of endogen bacteria, mostly located in human intestine. The process includes a first stage anaerobic, followed by others, provided from aerobic and anaerobic facultative bacterial groups. Besides bacteria, other microorganisms, like saprophyte fungi and diverse entomofauna act during putrefaction of cadavers.

There are four principal phases of human body decomposition – chromatic, gaseous, humorous and skeletonization – however, in the ambit of the present study, the gaseous and the humorous are the most important.

The gaseous period occurs normally during the first three weeks of decomposition (at air exposition of the body) and is typified by the formation of gases in different organs and tissue (CUESTA, 1986). These gases may cause the rupture of cavities and consequently release humorous liquids. Humorous phase is characterized by the dissolution of cellular elements and the consequent liquefaction of tissue resulting in the production of lixiviates. This phase may occur during several months (CUESTA, 1986), or even years, depending of the structure of the cadavers and the burial conditions (FÁVERO, 1980). The rupture of the abdominal cavities may be accompanied for lixiviation of humorous liquids. The leakage from the disposal sites of the buried human bodies is very slow and the most part of the water evaporates simultaneously when it is released and only observed around the burial site. However, the unsaturated zone will be impregnated with fatty substances, and intermediate non volatile products, resulting from the process of decomposition. Subsequently these products can be percolated through the soil to the water taken after precipitation, and contaminate the groundwater.

Factors that interfere with putrefaction

In average human bodies are consisting of 64% of water, 10 % of lipids**, 6,4% proteins,** 5% of mineral salts and 1% of carbohydrates (VAN HAAREN, 1951) and takes around ten years to decompose in Portugal. Duration of decomposition steps is influenced by several intrinsic and extrinsic factors. The intrinsic factors are related to the cadavers, like age, sex, height, race, cause of dead or if it is was made an autopsy. Extrinsic factors are related with the environment around the body, like environmental temperature, precipitation, depth of burial and soil oxygenation (depending on type of soil), which can accelerate, retard or even stop the decomposition process (RODRIGUEZ and Bass, 1985). MANN *et al.* (1990) classified the variables intervenient in the decomposition of bodies and found that the most important are the temperature, the access to insects and depth of burial.

Estimation of contaminant flux

The amount of liquids lixiviate produced from a cemetery is related with the dimension of it.

Table 1: Example of estimates of effluent concentrations at a small (I) and large municipal cemetery (II) in UK

Year	Cumulative area of burials (m^2)		Annual effluent production (liters)	
	I	II	I	II
1	125	4 375	25 000	918 750
2	250	8 750	50 000	1 837 500
3	375	13 125	75 000	2 756 250
4	500	17 500	100 000	3 675 000
5	625	21 875	125 000	4 593 750
6	750	26 250	150 000	5 512 500
7	875	30 625	175 000	6 431 250
8	1000	35 000	200 000	7 350 000
9	1125	39 375	225 000	8 268 750
10	1250	43 750	250 000	9 187 500

Adapted from YOUNG *et al.,* 1999

Risk of contamination

Shallow groundwater protected by a thin unsaturated zone, composed of coarse grained or fissured materials must be avoided in order to site cemeteries because is potentially vulnerable to contamination, since it has high permeability and low capacity of retention of contaminants. Also fine soils where prevail anaerobic conditions, even if the filtration zone is above the water table, must be avoided in order to site cemeteries (ENGELBRECHT, 1998). An unsaturated zone underneath a cemetery increases the opportunity for attenuation of the seepage during decomposition of corpses (WHO, 1998). Carsick aquifers, with a very small vadose zone have weak capacity of filtration and are not adequate to cemeteries. The most useful soil type to maximize retention of degradation products is finergrained non-fissured material, as clay-sand mix of low porosity, and a small to fine grain texture (WHO, 1998).

This project has been carried out to provide information about the potential risks to groundwater resources associated with siteing of cemeteries.

Cases of study

The principal criteria used to select the cemeteries were geological and hydrogeological characteristics of the area of implantation of cemeteries and the proximity with groundwater sources (domestic or public), with the objective of evaluating the response of areas with different characteristics to the contamination process.

MATERIALS AND METHODOLOGY

Selection of the study areas

The three study areas selected are located in the north (Seixas, District Viana do Castelo) and south (Querença and Luz de Tavira, District Faro) of Portugal. Both cemeteries were constructed between the end of the the nineteenth and the beginning of twenteth. Climacteric conditions from north to the south of Portugal are very different. In the north the prevailing climatic conditions are moderate summers and strongly determined by rain and humidity in winter. The climatic conditions have a Mediteranean character in the south. The three cemeteries are located in areas with different geologies. Concerning the hydrogeology, Querença is located in a karst aquifer and Luz de Tavira in a porous aquifer. At Seixas the groundwater table was under the influence of the tides of Rio Minho.

Water samples were collected for bacteriological, physical and chemical testing between September 2000 and September 2001, each two months. At Querença no sample points where inside of the cemetery. Instead seven sample points of groundwater located in a radius of 800 meters around the cemetery were monitored: P1, P2, P3, P4, P7 and P8 artesian wells and a well, P5. At Luz de Tavira two wells were studied: P6 and P9: The first was inside of the cemetery and P9 at 300 meters of distance. Seixas cemetery had also a well inside of the cemetery (P10). Groundwater was extracted for different purposes (drinking, irrigation and ornamentation). On-site sewage disposal had been were also localized in the area around the cemeteries.

Testing water quality

The hydro-chemical study of groundwater involved the analyses of the following determinants: temperature (T) pH, electrical conductivity (EC), nitrites (NO_2), nitrates (NO_3), ammonium ion (NH_4), chloride (Cl), oxidizability, total phosphorous (P), calcium (Ca), magnesium (Mg), hardness ($CaCO_3$), sulphates (SO_4), sodium (Na), potassium (K), total zinc (Zn), total lead (Pb) and total organic carbon (TOC).

Water samples were analyzed for fecal-indicator organisms. Indicator organisms are bacteria whose presence in drinking water indicates that pathogens may be present. Indicator organisms are easier to detect and test for than the pathogens themselves. It were studied total coliform, fecal coliform and fecal streptococci and sulfite reducer clostridia, indicator of remote contamination. Heterotrophic bacteria (growing at 22 and 37 ºC), and proteolytic bacteria with capacity to produce extra cellular enzymes were also determined by the method usually used in food microbiology (VERA e Dumoff, 1974), adapted by MARTINS *et al.* (1991). Water samples were processed by use of membrane filtration techniques (0.45 µm pore-size membrane filters), incorporation media and most probable number (MPN).

Additionally, it was promoted a geophysics study in the area around Querença cemetery.

RESULTS

The bacteriological results are presented in table 2 and graphics.

Table 2: Microbiological groundwater contamination

Sample points		Bacteriological parameter (1) (Minimum and maximum interval)						
		GT22	GT36	T C	F C	T E	CSR	PROT
Querença	P1	2-132	2-670	0-300	0-475	0 - 3	23->1100	0- 130
	P2	29-1696	24-1575	35-750	1-530	0-28	43-240	0- 180
	P3	9-1420	440-1380	10-480	0-1800	0-282	93-2400	0- 94
	P4	20-29560	61-28560	130-6900	0-4400	0 - 6	7-460	0- 180
	P5	81-580	36-680	10-2600	3-330	1-110	0-43	0
	P7	3-133	13-400	0-23	0-20	0 - 4	4-93	0- 280
	P8	21-5020	25-4700	46-1900	0-395	1-128	23-4600	0- 94
Luz de Tavira	P6	27-365	1-1100	3-1850	1-121	0-11	23-1100	0-90
	P9	1-293	2-293	0-595	0-60	0 - 7	0-48	2-90
Seixas	P10	5-4800	6-2610	193-3900	0-4400	0-580	4-4600	nd (2)
	P11	5 3	2 4	4 9	4	0	4	nd (2)

(1) GT22, GT36=CFU/1ml total germs, heterotrophic, mesophile growing at 22 ºC and 37 ºC, respectivly; TC, FC and FE=CFU/100 ml of total coliform, fecal coliform and fecal streptococci ; CRS=NMP/100ml of sulfite reducer clostridia

(2) nd= no data

DISCUSSION OF RESULTS

The high levels of bacteriological contamination found in the most of the sampled points showed that the three cemeteries might constitute potential sources of contamination of groundwater.

Analysis from the cemetery water of Luz de Tavira (P6) showed higher levels of bacteriological and physical-chemical parameters when comparing with a well placed about 300 meters (P9).

At Querença physical and chemical quality of water reflect the different hydrogeology characteristics of the carsick aquifer where the cemetery is placed. In general, the samples from P3 and P4 showed much higher levels of bacteriological contamination. The geophysics study in the area showed high carsification in this direction. The samples showed low levels of the heavy metals Pb and Zn.

In Seixas the samples of water collected from a well sited inside of the cemetery (P10) showed increased levels of the bacteriological indicators analyzed, when compared with a spring 290 meters away from the cemetery (P11).

Sources of fecal-indicator bacteria include septic system failure or improper septic system construction or design. At Seixas there was municipal sludge treatment of wastewater and no other sources of organic contamination could be found close to the cemetery, this lead to the assumption that the obtained results are directly related to the presence of the cemetery. However that wasn't the case at the other two areas studied. The results from Querença were not conclusive with respect to determining the influence of cemetery contamination on groundwater, despite the fact that high levels of chemical and bacteriological contamination were detected in all the boreholes sampled. Since it is a karst aquifer and due to the existence of many septic tanks in the area, this can mask the impact from the cemetery. Although, there are indications that the closest sampling point from the cemetery must be under the influence of the cemetery, specially during high level of groundwater after periods of precipitation.

CONCLUSION

The results obtain conduce us to the conclusion that cemeteries may contribute to groundwater contamination.

Portuguese legislation gives protection perimeters to public captations of groundwater from cemeteries within Zone 1 and Zone 2 under the Regulation 382/99, 22 of September. We believe that is important to review the Portuguese legislation concerning with siteing of cemeteries. Site-specific risk assessments should be conducted for cemetery site selection, taking into account the geological and hidrogeological conditions, proximity of receptors, such as water supply boreholes and springs, as well as other environmental factors, in order to protect the groundwater and provide a normal process of body decomposition. World Health Organization (WHO) proposes that human or animal remains must not be buried within 250 meters of any well, borehole or spring from which a potable water supply is drawn and that place of interment should be at least 30 meters away from any other spring or watercourse and at least 10 meters from any field drain. This distance may be greater if the site has a steep hydrogeological gradient or the velocity of groundwater flow within an aquifer is rapid (WHO, 1998).

The scope of groundwater contamination from cemeteries must not be generalized.

ACKNOWLEDGMENTS

The authors wish to express their thanks to all the homeowners who kindly permitted the sampling of their private water wells, to *Direcção Regional do Ambiente e Ordenamento do Território - Algarve* that carried out physical-chemical water analyzes, to *Universidade do Algarve* that lent the laboratory installations to proceed to bacteriological analyses and to *Águas do Algarve S.A.* which gave financial support to the geophysics study. Without them this study wouldn't be possible.

REFERENCES

BASTIANON, D., Matos, B. A., Aquino, W. F., Pacheco, A. and Mendes, J. M. B (2000). *Geophysical surveying to investigate groundwater contamination by a cemetery*. The Annual Meeting of the Environmental and Engineering Geophysical Society. Arlington. 709-718.

BECKS, P. M. (1997). *Soil and Groundwater contamination from cemetery leachate*. M.S. Thesis, University of Toledo. 107 pp..

CUESTA, J. M. R. de la (1986). *Informe solicitado por* NEMOSA. Comunicação pessoal não publicada. Madrid.

ENGELBRECHT, J. F. P. (1998). *Groundwater pollution from cemeteries*. The Water Institute of Southern Africa, Biennal Conference and Exhibition. **1**: 1-8.

FÁVERO, F. (1980). *Medicina Legal*. 11ª Ed. Vol. **2**. Belo Horizonte. Itatiaia. 500-566.

FISHER, G. J. and Croukamp, L. (1993). *Ground Water Contamination and it's Consequences, Resulting from the Indiscriminate Placing of Cemeteries in the Third World Context*. Conference Africa Needs Groundwater. University of the Witwatersrand. Johannesburg.

MANN, R. W., Bass, W. M. and Meadows, L. (1990). *Time Since Death and Decomposition of the Human Body: Variables and Observations in Case and Experimental Field Studies*. **J Forensic Sci**. **35** (1): 103-111.

MARTINS, M. T., Pellizari, V. H., Pacheco, A., Myaki, D. M., Adams, C., Bossolan, N. R. S., Mendes, J. M. B. and Hassuda, S., (1991). *Qualidade bacteriológica de águas subterrâneas em cemitérios*. **Rev. Saúde Públ**. **25** (1): 47-52.

MATOS, B. A. (2001). *Avaliação da ocorrência e do transporte de microrganismos no aquífero freático do cemitério de Vila Nova Cachoeirinha, Município de São Paulo*. Tese de Doutoramento. Instituto de Geociências da Universidade de São Paulo. 114 pp..

MATOS, B. A. and Pacheco, A. (2000). *Ocorrência de microorganismos no aquífero freático do cemitério Vila Nova Cachoeirinha*. I Congresso Mundial Integrado de Águas Subterrâneas. Fortaleza: 1-11.

PACHECO, A., Mendes, J. M. B., Martins, T., Hassuda, S. and Kimmelmann, A. A. (1991). *Cemeteries – a potential risk to ground water*. **Wat. Sci. Tech. 24** (11): 97-104.

RODRIGUEZ, W.C. III and Bass, W. M. (1985). *Decomposition of Buried Bodies and Methods That Aid in Their Location*. **J Forensic Sci**. **30**. (3): 836-852.

VAN HAAREN F. W. J. (1951). *Cemeteries as sources of groundwater contamination*. (em neerlandês). **Water**. **35** (16): 167-172.

VASS, A. A., Bass W. M., Wolt, J. D., Foss, J. and Ammons, J. T. (1992). *Time Since Death Determinations of Human Cadavers Using Soil Solution*. **J Forensic Sci**. **37**. (5): 1236-1253.

VERA, H. D. and Dumoff, M. (1974). *Culture media. In: Manual of clinical microbiology. LENNETTE et al. (ed) American Society for Microbiology*: 881-929.

YOUNG, C. P., Blackmore, K. M., Reynolds, P. J. and Leavans, A. (1999). *Pollution Potential of Cemeteries*. Water Research Center R&D. Project Record P2/024/1 for the Environment Agency. 105

WHO, Regional Office for Europe. (1998). *The impact of cemeteries on the environment and public health – an introduction briefing*. World Health Organization. EUR/ICP/EHNA 01 04 01 (A). 1-11.